FAILURE ANALYSIS AND RESIDUAL LIFE ESTIMATION USING A MIXED METHOD OF X-RAY FRACTOGRAPHY AND SIMULATION

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Abstract

In order to guarantee passengers safety while improving rolling stock maintenance, the French railroad company, SNCF, studies the evolution of cracks that can propagate in fatigue loading situations, particularly for locomotive axles. This research aims to determine the crack propagation history, which is a determining factor in maintenance, studying fracture surfaces while combining X-ray fractography analysis and numerical methods for variable amplitude loads.

1. Introduction

Determining the crack propagation history requires first to precisely define the propagation behavior of the axle material (usually made of 2 types of materials : A1N (C40) and A4T (25CrMo4)), including all the considered stages (I: initiation; II: propagation; III: fracture). Nasgro's propagation model (equation (1)) includes these specific stages [1] from the moment the crack is progressing very slowly near the stress intensity factor (SIF) threshold ΔK_{th} to the one close from the fracture defined by the fracture toughness K_c :

$$\frac{da}{dN} = C\left(\frac{1-f}{1-R}.\Delta K\right)^n . \frac{\left(1-\frac{\Delta K_{th}}{\Delta K}\right)^p}{\left(1-\frac{K_{max}}{K_c}\right)^q} \qquad (1)$$

where a is the crack length, N, the number of loading cycles, R the stress ratio $f = K_{op}/K_{max}$ with K_{op} the stress intensity factor needed to open the crack and K_{max}, the maximum observed SIF during a loading cycle. C, n, p and q, parameters to be identified from a specific experimental database. Since the SNCF material is subject to High Cycle Fatigue with most of the time variable loading amplitude, the crack propagation models highly depends on the SIF threshold ΔK_{th} because of the number of low damaging cycles considered. This threshold ΔK_{th} is being determined by experiments on CCT (Center-Cracked Tension) specimens for very slow crack propagation speeds : $da/dN \in [10^{-9}; 10^{-10}]$ m/cycle. During the experiment, the crack length was measured by post-treated pictures and DCPD (Direct Current Potential Drop) to be able to track at least tenths of a millimeter crack propagation.

Nevertheless, the determination of ΔK_{th} is influenced by the material microstructure and varies from one sample to another. The number of cycles that may induce propagation changes depending on the specimen threshold. The determination and analyses of ΔK_{th} will result in a probabilistic model for crack propagation with the dependence for ΔK_{th} on the crack propagation to be generalized as a distribution model for the propagation behavior. This distribution model is then implemented as an input for the numerical simulation code that computes the crack propagation rate and length considering a given loading spectrum. Monte-Carlo methods are used to estimate the computed propagation distribution that can be statistically compared to experiments. The simulation model (Fig 1.) is performed using an extended finite element method (XFEM) that is coupled with an incremental procedure that considers non linear effects of the loading on the material locally at each step. It allows us to compute SIF fields close to the crack and to evaluate the plastic zone.

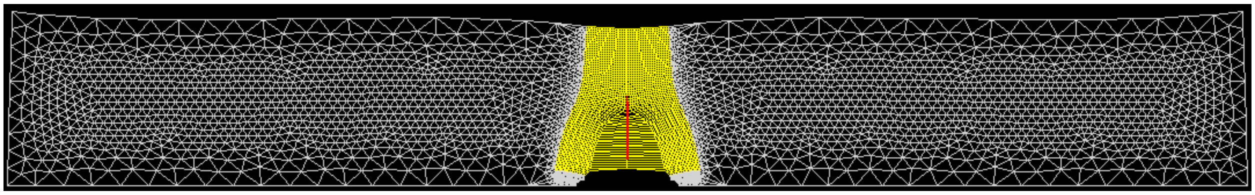

Fig.1 – Crack propagation, in red, simulated with an XFEM model for half a CCT geometry

The computed SIF fields will then be compared to SIF fields measured by X-ray diffraction on the experimental samples. The SIF fields comparison model running would allow us to find back, with an inverse model, the loading levels that could have generate the measured crack and estimate at the end the crack residual life.

Bibliography

[1] Dirik, H., & Yalçinkaya, T. (2016). Fatigue crack growth under variable amplitude loading through XFEM. Procedia Structural Integrity, 2, 3073-3080.